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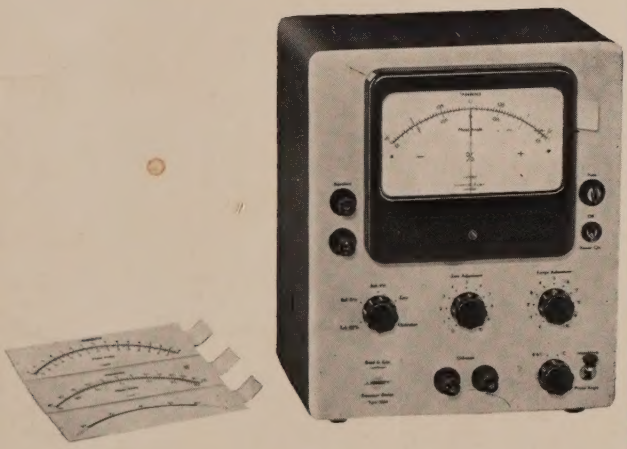
1504

INSTRUCTIONS AND APPLICATIONS

Deviation Bridge Type 1504



Adapted for the checking of resistors, capacitors and inductors in industrial production and laboratories.

- Beat frequency oscillators
- Low frequency oscillators
- Deviation test bridges
- Strain gauge apparatus
- Frequency measuring bridges
- Distortion measuring bridges
- Heterodyne voltmeters
- Audio frequency spectrometers
- Frequency analyzers
- Level recorders, a. c. and d. c.
- Automatic frequency response recorders
- Automatic A. F. spectographs
- Logarithmic potentiometers
- Noise level potentiometers
- Recording paper
- Polar diagram recorders
- Vacuum tube voltmeters
- Wide range vacuum tube voltmeters
- Diode voltmeters
- D. C. voltmeters
- Megohmmeters
- Microphone amplifiers
- Impact sound generators
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(1)

DEVIATION BRIDGE

Type 1504

PROPERTY OF ENGINEERING
TEST EQUIPMENT
CROSLEY, DIV. OF AVCO

ITEM 3 COPY 1

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Deviation Bridge Type 1504

Description

The Deviation Bridge is intended for testing components such as resistors, capacitors and inductors, and will read directly in per cent any deviation of impedance and phase angle from a chosen standard. The instrument comprises a built-in generator supplying a wheatstone bridge with an a.c. voltage af frequency 1000 c/s (see the diagram of fig. 1). The wheatstone bridge consists of two resistor arms built in the instrument, while the remaining arms are formed by the external standard and the measuring object. The diagonal voltage is fed through a two-stage amplifier to a demodulator circuit together with the generator voltage. A d.c. meter in this last circuit indicates the per cent deviation from the standard, reading the impedance

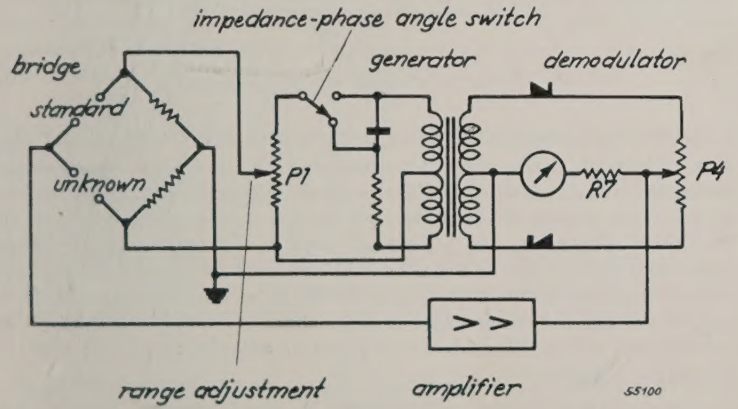


Fig. 1. Principle of the Deviation Bridge type 1504.

deviation when the bridge supply voltage is in phase with the generator voltage, or the phase angle deviation when the bridge supply voltage is shifted 90° in phase by means of a push-button switch.

The advantages of the demodulator principle compared with a circuit where a rectifier is directly inserted in the output stage of the amplifier, are to be found in the phase sensitivity, so that the meter shows a positive or negative deflection for positive or negative deviations from the standard, and in the relative insensitivity to hum and noise voltages, which would otherwise influence the measuring results, the demodulator only responding to signals of the same frequency as the generator.

In the zero position, adjustable by means of potentiometer P_4, the indicating instrument, with its zero point in the middle of the scale and its deflection dependent on the direction of the current, will be without current, and will be insensitive to changes in the generator voltage. A deviation in the unknown component from positive to negative as compared with the standard, implies a phase change of 180° in the diagonal voltage compared with the generator voltage, causing opposing currents in the indicating meter and consequently opposing deflections.

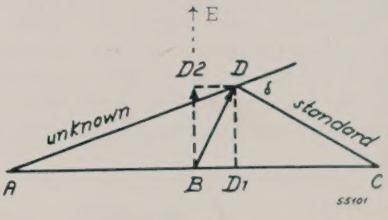


Fig. 2. Vector diagram of bridge voltages.

A vectorial representation as shown in fig. 2 elucidates this better and likewise explains the phase angle measurement. AC is the bridge supply voltage with mid point B grounded via the two fixed resistors. The standard and the unknown component, differing in both amplitude and phase angle, divide the bridge voltage into the vectors AD and DC. The galvanometer voltage is consequently BD, and would as such be measured by an ordinary a.c. voltmeter. The effect of the demodulator circuit is to send an intermittent d.c. current through the meter which is proportional to that component of the galvanoment voltage BD which is in phase or anti-phase with the EMF E_1 driving the demodulator.

With the zero-adjustment potentiometer P_4 in mid-position, equal current pulses will flow through resistor R_7, in opposite directions, during the half period in which the rectifiers q_1 and q_2 are open. The meter indication will thus be zero. With a small extra a.c. voltage inserted across R_7, this equilibrium will be disturbed in a manner which depends on the phase difference between E_1 and the incoming signal voltage. With a phase difference of 0°

and 180°, there will be an extra current flow through R_7 in one or the other direction, corresponding with the value of the a.c. voltage. With 90° difference between the phase of E_1 and the galvanometer voltage there will be currents in both directions, equal in size, and the meter reading will be zero. It is thus easily seen that only the vector component of the galvanometer voltage in the direction of the demodulator voltage will be indicated by the meter.

Consequently, with the bridge supply voltage in phase with E. M. F. E_1, the component BD_1 of the galvanometer voltage will be measured. With small angle δ, i. e. the difference in phase angle between standard and unknown, this component will indicate the difference in magnitude between standard and unknown. With 90° phase difference between the bridge voltage and E_1, (obtained by means of the RC divider in fig. 1), the voltage BD_2 will be measured. With δ small, we have BD_2 proportional to tan $^1/_2$ δ, and consequently a measure for the phase angle deviation. One advantage more of the applied circuit is the possibility of checking whether the amplifier is overloaded or not. In case the deflection stays within full scale for both impedance and phase angle measurement (where it does not matter whether these deflections are positive or negative), the vector BD, or input signal to the amplifier, will always be below the permitted limit. Without the possibility of measuring both components of the diagonal voltage, it should be necessary to imply the condition that the phase angle of both standard and unknown should be about equal, because otherwise the galvanometer voltage might exceed by far the deviation component, overload the amplifier and cause an erroneous measuring result. This means also that inductors with considerable resistance losses can be measured with this deviation bridge.

The scale calibration is made in the factory in the following manner:

Impedance: A 1000 Ω standard resistor is used as the standard, and a resistor variable in steps of 1 Ω around 1000 Ω as the unknown. The meter must indicate 0, when the "unknown" is 1000 Ω, + 1 % when it is 1010 Ω and so on. Shunting one of the 1000 Ω resistors with a capacitor of 1590 pF ($\frac{1}{\omega C}$ = 100,000 Ω at 1000 c/s, corresponding to a 1 % quadrature component) should give no deflection of the meter.

Phase Angle: A polystyrene capacitor of 159 nF ($\frac{1}{\omega C}$ = 1000 Ω at 1000 c/s) is used as the standard, and a capacitor of equal capacity and power factor, series connected with a resistor, variable in steps of 1 Ω, as the unknown. The meter must indicate 0 when the series resistor is 0, even when one of the capacitors is increased by 1 %. A series resistor of 10 Ω must give a meter deflection of 1 %, to the one side when the resistor is in series with the "unknown", and to the other when it is in series with the "standard".

It will be obvious from the above procedure that, taking the "standard" as a base, the meter will read the in-phase (for impedance deviation) or quadrature (for phase angle deviation) component of the deviation of the "unknown" from the standard. For impedance deviations, this is in accordance with usage for resistors and inductors, whereas capacitors usually are characterized

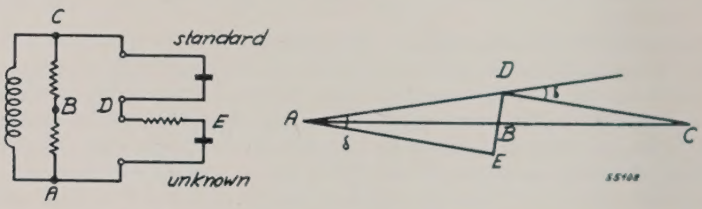


Fig. 3. Vector diagram of bridge voltages under calibration procedure.

by their capacitance deviation. To permit a direct reading of % deviation of capacity, the bridge has consequently a switch for interchanging the standard and unknown connections, when the switch is set to the "C" position. For phase angle measurements, a modified version of the vector diagram is given in fig. 3, corresponding to the meter calibration procedure. AC is the bridge supply voltage, with the grounded mid-point B. The voltages EA and DC across the condensers are equal in magnitude and phase and the vector ED, 90° out of phase, represents the voltage across the loss resistor (in figure 3, ED is 30 % of AE). The meter reading is $\frac{ED}{AE} \times 100\,\% = \tan\delta$ $\tan\delta$ is almost equal to δ in radians; at the maximum reading of 30 %, as in fig. 3, $\tan\delta$ is 0.3 and $\delta = 0.291$ radian.

Different dials can be inserted in the large square type indicating instrument, as shown in the photograph of the instrument, fig. 4. The bridge has three ranges, each with a corresponding dial, while three blank dials are delivered for special purposes, e. g. indicating manufacturing tolerances during checking components.

The ranges are:

Impedance Deviation	Phase Angle Deviation (tan δ)
$-1.5\,\%$ to $+1.6\,\%$	-1.5 to $+1.5 \cdot 10^{-2}$
$-7\,\%$ to $+8\,\%$	-7 to $+7 \cdot 10^{-2}$
$-25\,\%$ to $+35\,\%$	-30 to $+30 \cdot 10^{-2}$

To adjust the instrument on any of these three ranges a set of resistors is included, the ratios of which are indicated by the red markings on the meter scales. With potentiometer P_1, "Range Adjustment", the bridge voltage is

adjusted until these scale deflections are obtained. Both impedance and phase angle indications will then be correct. The drift from the reference position is very small and need only be checked once an hour.

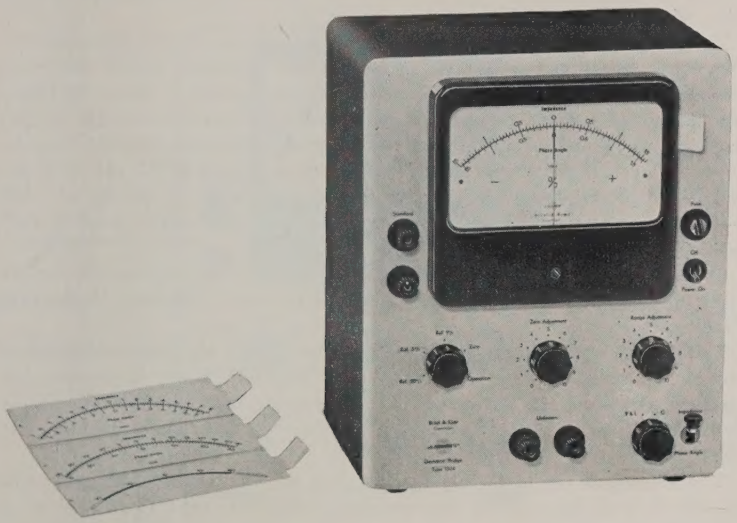


Fig. 4. Photo of Deviation Bridge type 1504.

When the deviation indicated is zero, the real deviation is less than 0.03 %. The full scale accuracy is better than 3 % of the reading. (See also p. 12). The moving coil instrument is slightly under-critically damped to secure maximum speed and is perfectly protected against overload.

As previously mentioned, the bridge is to a certain extent insensitive to hum voltages owing to the fact that the demodulator responds only to voltages having the generator frequency. However, when the hum voltage is so high as to saturate the amplifier, the gain will decrease and the meter reading will be too low.

When measuring high impedances the meter reading will also be too low, because the bridge is loaded by the amplifier input circuit. This is compensated for within the stated accuracy by increasing the generator voltage according to adjustment curves, whose values are used instead of the red markings on the scale. (See p. 26).

The measuring range for the type 1504 Bridge covers resistances between 10 Ω and 10 MΩ, capacitances between 50 pF and 10 μF, and self-inductances

between 2 mH and 100 H, approximately. These values are valid for all % deviation ranges. On the 30 % range also R values below 10 Ω, L values below 2 mH and C values higher than 10 μF can be measured. The oscillator load is then too small however to deliver the necessary bridge voltage on the other % ranges.

The bridge may be used as a direct reading instrument for capacitances. Two equal capacitances are connected across the "Standard" and "Unknown" terminals, the capacitance to be found is placed parallel to either of these two "Standards", and its value then measured as a per cent increase of the fixed known value. By varying the fixed known capacitance, different measuring ranges can be obtained. 100 pF will give the ranges 0—1.5 pF, 0—8 pF and 0—3.5 pF, while 10 μF will give the ranges 0—0.15 μF, 0—0.8 μF and 0—3.5 μF, corresponding to the meter deflections of 0—1.5 %, 0—8 % and 0—35 %.

By using two fixed resistors the bridge can similarly serve as an ohmmeter. The resistance to be measured is connected in series with one of the two fixed resistors.

Finally, the apparatus may be used for measuring and controlling other physical quantities which are transferable into impedance variations; for instance, stress may be measured by the change in the resistance, permeability or conductivity of the material, temperature by the change in resistance etc.

The European model is intended for use on 115, 127 or 220 volts a.c., 40—60 c/s. Switching to the different line voltages is made by means of a screwdriver through a hole in the back plate. A pilot disc ganged with the switch indicates the line voltage to be connected. The American model is designed for 115 volts, 60 c/s. The power consumption for both models is about 40 watts. The plate voltages to the amplifier are stabilized by a neon tube. A variation of 10 % in the power voltages will influence the meter deflection by about 2 %, the zero point being independent of the line voltage.

Operation

The apparatus is connected to a power line of the voltage stated on the back. When the current is switched on, the meter lamps will light immediately, and in about 30 seconds the tube cathodes will be warm.

The standard and the object to be measured are connected to the terminals of the apparatus, and the meter pointer is set to 0 by means of the knob marked "Zero", the selector to the left of the apparatus being set to position "Zero". (See fig. 5).

Depending on the deviation range one wishes to measure, one of the three removable dials is placed in the meter of the instrument. The selector is set

to the corresponding position "Ref. 1 %", "Ref. 5 %" or "Ref. 20 %", and the knob marked "Range Adjustment" is turned until the pointer stands on the red marking on the scale. The selector is then turned to "Operation", and the apparatus is ready for use

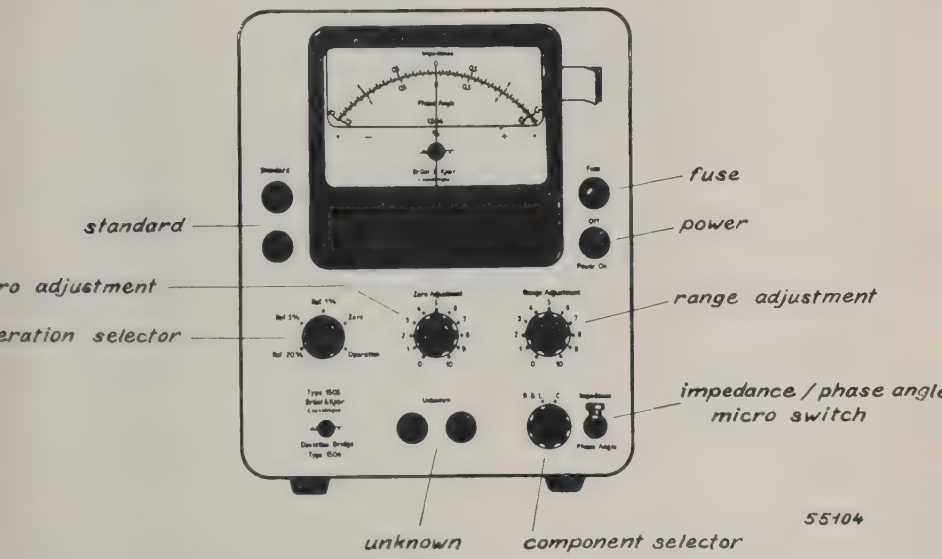


Fig. 5. Drawing of Deviation Bridge type 1504.

The adjustment may drift a little, particularly during the first few minutes, and should therefore be checked at intervals. A friction brake is placed under the knobs for "Zero" and "Range Adjustment", so as to make the potentiometer adjustment heavy, whereby accidental handling will not cause the adjustment to change.

When measuring high impedances, the values obtained from the adjustment curves as shown on p. 26 should be used for the range adjustments, instead of the red markings on the scales.

The switch on the right of the apparatus has two positions: "R & L" for measurement of resistances and inductances, and "C" for capacity measurements. To the right of this knob there is a microswitch for quick switching from impedance to phase angle measurements. The rest position of this switch is upwards on "Impedance", while only a small pressure is needed to switch over to "Phase Angle". In the latter position the switch can also be set fixed.

When making phase measurements the positive (right) or negative (left) deflection on the meter scale indicates the loss in the "unknown" capacitor or inductor, as well as a capacitative or inductive influence on resistors, according to the table below.

	Positive deflection	Negative deflection
R	Inductive influence. R in series with small L.	Capacitative influence. R in series with big C, or R in parallel with small C.
L	(**N.B.**, this is only valid when the component selector is on R)	The loss in the "unknown" is higher than in the "standard". If there is no loss in the standard inductor, the negative deflection indicates directly the loss factor δ of the unknown inductor. $\delta \approx \frac{Rs}{\omega L} \approx \frac{\omega L}{Rp}$ $Rs = \delta^2 . Rp$ where R_s represents the series loss resistance and Rp the parallel loss resistance. (**N.B.** This is only valid when the component selector is on L).
C		The loss in the unknown" is higher than in the "standard". If there is no loss in the standard, the negative deflection indicates directly the phase angle or dissipitation factor δ of the component. $\delta \approx \omega . C . Rs \approx \frac{1}{\omega . C . Rp}$ $Rs = \delta^2 . Rp$ where R represents the series loss resistance and R the parallel loss resistance. (**N.B.** This is only valid with the component selector on C).

This table follows directly from fig. 2, which is valid for R and L measurements with the unknown and standard placed as shown. With impedance measurements the components of the diagonal voltage in the direction of BC give a positive meter deflection and also indicate a positive deviation between unknown and standard. With phase angle measurement the demodulator voltage is turned 90° in the direction BL, and a diagonal

voltage component such as BD_2 will give once more a positive meter deflection.

With **resistances** both a positive and a negative BD_2 are possible, indicating an inductive or capacitative influence, assuming the standard to have zero phase angle.

Inductances with losses can be interpreted as complex inductances, $\overline{L} = L \cdot e^{-j\delta}$, and explained as a series or parallel combination of L and R_s or R_p. It can be easily calculated that

$\tan\delta = \dfrac{R_s}{\omega L_s}$ in the series case, and

$\tan\delta = \dfrac{\omega L_p}{R_p}$ in the parallel case.

For small δ, $\tan\delta = \delta$, and the relation $R_s = \delta^2 \cdot R_p$ follows.

Assuming the standard to have no loss, only a negative BD_2 component will be possible, giving a negative angle between the two vectors "unknown" and "standard". The negative meter deflection will thus indicate directly the loss factor of the component.

Capacitances with losses can likewise be interpreted as complex capacitances, $\overline{C} = C \cdot e^{-j\delta}$, and explained as a series combination of C and R_s (small), or parallel combination of C and R_p (large) We have

$\tan\delta = \omega \cdot C_s \cdot R_s$ in the series case, and

$\tan\delta = \dfrac{1}{\omega \cdot C_p \cdot R_p}$ in the parallel case.

For small δ again the relation $R_s = \delta^2 R_p$ follows.

Also with vector representation, it follows directly that only a negative angle can exist between C (complex) and C (without loses).

With capacitance measurements, however, the standard and unknown connections are reversed, to allow a positive meter deflection for a positive deviation of the value of C between unknown and standard.

The two vectors for standard and unknown now represent $\dfrac{1}{C}$ and $\dfrac{1}{C} = \dfrac{1}{C} e^{+j\delta}$, and consequently a positive δ will produce a negative deflection the meter scale, indicating once again the phase angle or dissipation factor of the measured component.

With measurements on big capacitors, the resulting capacitive load for the oscillator (e.g., 5 μF when checking two 10 μF capacitances) will produce a phase shift ε between the bridge voltage and the demodulator voltage. The diagonal voltage BD in fig. 2 will then be measured as two components, BD'_1 and BD'_2, which make the same small angle ε with BD_1 and BD_2. Both impedance and phase angle measurements will consequently show an error.

GROUND COMMUNICATIONS SECTION

Strictly speaking this is also the case with smaller capaciters or with inductors but the introduced fault is then small compared with the measuring accuracy.

With an impedance deviation reading of a % and a phase angle deviation reading of b % the accuracies on the 3 different % ranges are as follows:

20 %	Impedance accuracy	0,03 a + 0,01 b	For capacities up to 1 μF
		0,03 a + 0,02 b	at 10 μF
	Phase angle accuracy	0,03 b + 0,01 a	for capacities up to 10 μF
5 %	Impedance accuracy	0,03 a + 0,02 b	for capacities up to 0,5 μF
		0,03 a + 0,05 b	at 3 μF
		0,03 a + 0,12 b	at 10 μF
	Phase angle accuracy	0,03 b + 0,02 a	for capacities up to 3 μF
		0,03 b + 0,05 a	at 7 μF
		0,03 b + 0,07 a	at 10 μF
1 %	Impedance acccuracy	0,03 a + 0,07 b	for capacities up to 0,5 μF
		0,03 a + 0,12 b	at 5 μF
		0,03 a + 0,16 b	at 10 μF
	Phase angle accuracy	0,03 b + 0,04 a	for capacities up to 0,5 μF
		0,03 b + 0,07 a	at 5 μF
		0,03 b + 0,14 a	at 10 μF

N.B. The zero accuracy of 0,03 %, is herewith not taken into account and should be added to all the above given accuracies.

To reduce hum voltages the apparatus should be grounded the holes in the nuts on the back plate. The standard and the objects to be measured should be placed together with the bridge on a grounded metal plate. None of the terminals of the apparatus is connected to the chassis. The upper of the terminals to the left and the terminal to the right at the bottom are connected to chassis through resistances of about 100 Ω and have an a.c. voltage of maximum 5 volts in relation to chassis. The other two terminals, marked in white, are mutually connected and lead to the input circuit of the amplifier.

If it is desired to measure objects having one pole grounded this pole should be connected to the right "Unknown" terminal and the grounding of the cabinet should be omitted. The capacity of the apparatus to ground is thus connected across one of the built in ratio resistances and should consequently be kept as low as possible.

With high impedance measurements (big R, small C), care should be taken that the connecting wires be held short, and placed in a similar manner, so as to take into account the introduction of parasitic capacities.

Furthermore, it is very important that no extra capacitance or leakage be introduced into the input circuit of the amplifier, i. e. between the chassis (or ground) and the two terminals marked in white.

APPLICATIONS

Measurements of Resistors and Capacitors in Production.

Fig. 6 shows a typical set-up for the Bridge when measuring resistors and capacitors in factory or stock-room. The Bridge itself should be placed on a table, on the under side of which a piece of metal foil or a thin metal plate is fastened, as a screen. This screen should also be connected to the earth connection of the instrument at the back. In this way, the whole measuring set-up will be sufficiently screened from hum voltages. The resistor or capacitor is placed in the Jig type 3901 mounted on the table and operated with the left lever. The silver contacts in the jig ensure a good contact to the wires of the object. The right lever operates the microswitch for impedance or phase angle measurements. With this arrangement it is possible to measure up to 4000 components per hour see also fig. 7).

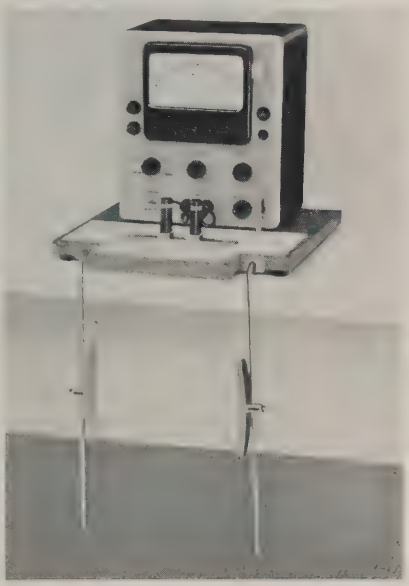


Fig. 6. Set-up of lever-operated contacts and screened table for checking large quantities of resistors and capacitors. The left lever operates the jig for the mounting of the components while the right one ensures a quick switching from impedance to phase angle measurement.

For convenience it is recommended that the standards be placed in our small Standard Box type ZR 1702, see fig. 8. This box has a circular base, to which two plugs are fixed at the correct spacing for connection to the Deviation Bridge. The standard resistance, capacitance or inductance is fasten

ed to these plugs, and a cylindrical cover placed over it. The value of the standard may be engraved on the cover. These boxes may then be mounted on a board fixed to the wall, having 4 mm holes drilled at 35 mm space, as shown in fig. 9. The holes are made vertically above each other, allowing the engraved values to be read in the correct position.

Fig. 7. Deviation Bridge type 1504 with the Jig type 3901 under operation.

An advantageous method of grading the standards is by use of the so-called "Preferred Numbers", or the "Standardized Renard Numbers" which are set forth in table I. These preferred numbers are based on a logarithmic scale and therefore give an even distribution of the chosen standard values. A particularly practical distribution is the R10 series, which divides a decade into 10 equal logarithmic steps. The values seen in the table, 1—1.25—1.6—2—2.5—3.15—4—5—6.3—8, are inscribed on the standards, whereas the exact value which the normals have is that which is given under the column headed "exact value", i. e. that value, the mantissa of whose logarithm is an integral number of times 0.1. For instance, the standard with the inscribed value 125 Ω should be 125.89 Ω and the standard which has inscribed 160 Ω, should be 158.49 Ω and so on. The use of logarithmically spaced standards gives a perfectly constant ratio between the individual values, and this ratio is uniform, no matter whether the resistors are 2, 3 or 4 % greater or smaller than the standard. This again means that one can construct attenuation series on the basis of the given standard values, as long as one takes components with the same percentage deviation from the standard values. A further

advantage with these "preferred numbers" is that an attenuator given in decibels is produced automatically, for, as can be seen from the figures, there is exactly 2 db difference between the standard values of the R10 series, 1 db difference between the values of the R20 series and ½ db difference between the values of the R40 series.

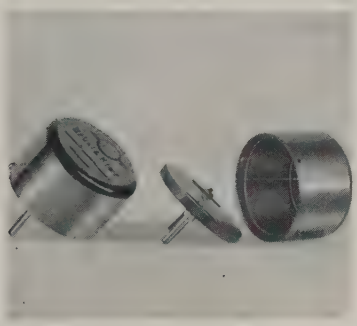


Fig. 8. Photo of the type ZR 1702 Box for Standards.

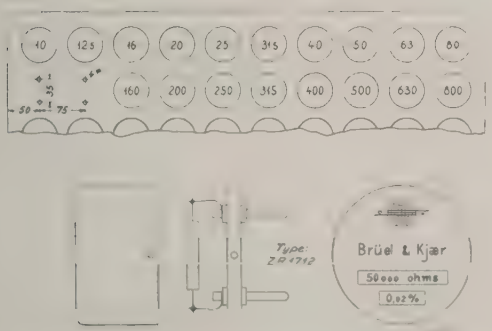


Fig. 9. Practical arrangement for standard resistance values. The standard resistances are placed in our Standard Box type ZR 1702.

40-series	20-series	10-series	5-series	Exact Value	Mantissa
1	1	1	1	10000	000
1.06				10593	025
1.12	1.12			11220	050
1.18				11885	075
1.25	1.25	1.25		12589	100
1.32				13335	125
1.4	1.4			14125	150
1.5				14962	175
1.6	1.6	1.6	1.6	15849	200
1.7				16788	225
1.8	1.8			17783	250
1.9				18836	275
2	2	2		19953	300
2.12				21135	325
2.24	2.24			22387	350
2.36				23714	375
2.5	2.5	2.5	2.5	25119	400
2.65				26607	425
2.8	2.8			28184	450
3				29854	475
3.15	3.15	3.15		31623	500
3.35				33497	525
3.55	3.55			35481	550
3.75				37584	575
4	4	4	4	39811	600
4.25				42170	625
4.5	4.5			44668	650
4.75				47315	675
5	5	5		50119	700
5.3				53088	725
5.6	5.6			56234	750
6				59566	775
6.3	6.3	6.3	6.3	63096	800
6.7				66834	825
7.1	7.1			70795	850
7.5				74989	875
8	8	8		79433	900
8.5				84140	925
9	9			89125	950
9.5				94406	975

Table I. Table for preferred numbers or Renard numbers standardized in the following countries:

Belgium: NBN 100 (1941), China: CIS No. 1 (1928), Czecho-Slovakia: CSN 1265 (1939), Denmark: DS 132 (1934), Finland: SFS AI (1933), France: X01-001 ENR 962-06 (1940), Germany: DIN 323 (1939), Great Britain: BS 1638 (1950), Holland: N 1270-1271 (1941), Hungary: NM 138 (1950), Italy: UNI 2016 (1942), Japan: IFS 4 (1925), Norway: NS 379 (1940), Sweden: SMS 400 (1932), Switzerland: VSM (10001 (1943), USA: Z 17.1 (1936), USSR: OCT 3530 (1925).

Table II shows a second standardized grading system for resistors and capacitors, according to the I.E.C. The three series E_{24}, E_{12} and E_6 are here composed of rounded values of the theoretical numbers $\sqrt[24]{10^n}$, $\sqrt[12]{10^n}$ and $\sqrt[6]{10^n}$, in which the exponent n is a whole positive or negative number.
The same remarks are valid in this case as for the Renard Numbers.

E 24	E 12	E 6
1.0	1.0	1.0
1.1		
1.2	1.2	
1.3		
1.5	1.5	1.5
1.6		
1.8	1.8	
2.0		
2.2	2.2	2.2
2.4		
2.7	2.7	
3.0		
3.3	3.3	3.3
3.6		
3.9	3.9	
4.3		
4.7	4.7	4.7
5.1		
5.6	5.6	
6.2		
6.8	6.8	6.8
7.5		
8.2	8.2	
9.1		

Table II. Series of preferred values for resistors and capacitors, according to I. E. C.

Measurements of Resistors and Capacitors in Laboratories.

In laboratories where resistors and capacitors are frequently measured, it will be a practical advantage to set up a couple of measuring bridges of type 1504 permanently connected to the resistor and capacitor standard, as indicated in fig. 10.

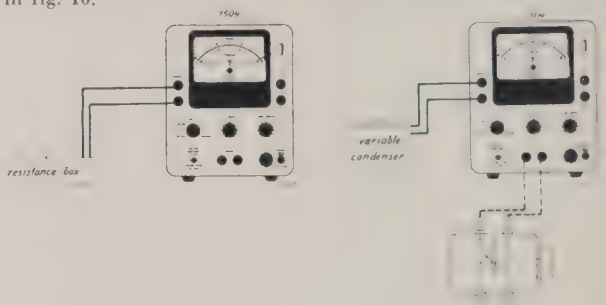


Fig. 10. Resistance box and variable condenser connected to Deviation Bridge type 1504.

Resistors are measured on 1504; the "Unknown" being connected to the Bridge, and the standard resistor being varied until the bridge is balanced. The unknown resistance can then be immediately found by reading off the value on the resistance box. This form of resistance measurement is much quicker in practice than adjusting a Wheatstone Bridge because the meter of 1504 responds much quicker than the usual light-spot galvanometer.

Capacitors may also be measured on 1504 in exactly the same way. In order to compensate for the connections to the variable condenser and its minimum capacity, the unknown capacitor should be connected via a small extra measuring box, containing a balancing capacity. In this way, a quick and very exact measurement of small capacitors can be carried out.

Checking of Coils for Short-Circuit Turns.

For checking coils in transformers, chokes, inductances etc., a set-up as indicated in fig. 11 is very useful. Two identical measuring coils with long iron cores are balanced on the bridge, and the coil under test is then placed over the end of one of the cores.

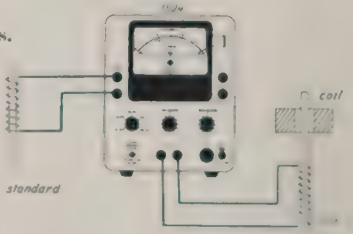


Fig. 11. Checking of coils.

If there is a short-circuit in the coil, the induction in the coil will react with the balanced coil and deflect the meter pointer. In most cases a phase angle measurement will give the highest sensitivity.

Balance of Ganged Variable Condensers and Potentiometers.

For adjustment of coupled variable condenser the set-up shown in fig. 12 will be practical. The two stators are connected respectively to the upper left and lower right terminals of the bridge, while the rotors, which are as a rule connected together, are joined to one of the two remaining terminals. The balance expressed in % deviation may then be checked for all positions of the rotor. A similar set-up can be used with ganged potentiometers and variable resistors.

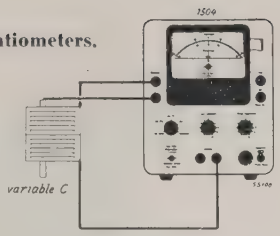


Fig. 12. Matching of variable condensers.

Checking of Transformers.

The Deviation Bridge is also a suitable apparatus for checking transformers for amplifiers, hearing aids, etc. The set-up is shown in fig. 13. The transformer with its correct load on the output side is connected to the terminals marked "Unknown". A perfect transformer loaded with the same impedance is used as standard, and defects in either coils, turn numbers or laminations may then be observed. When measuring high-impedance transformers it may happen that the capacity is so high that it will disturb the measurements even on type 1504. Such transformers have to be measured at a very low frequency.

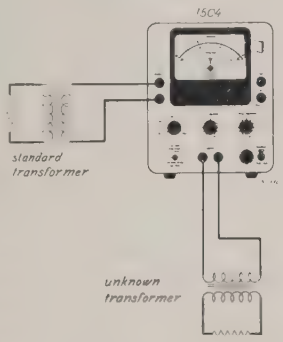


Fig. 13. Production testing of transformers.

Direct-Reading Measurements of Capacitances.

The Deviation Bridge type 1504 may be used as a direct-reading instrument for measuring capacitances. Two equal condensers of exactly known capacitances are, as shown in fig. 14, connected across the "Standard" and "Unknown" terminals, one to each terminal. The capacitance to be found is measured as a per cent increase of the fixed known value. By choosing the fixed condensers as pure powers of 10 the direct readings will be simplified. To make the adjustment easier it will be practical to have part of the capacitance on "Standard" placed as a small trimmer condenser.

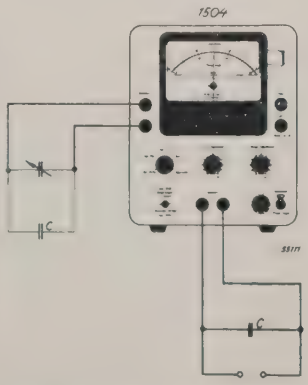


Fig. 14. Direct reading measurements of capacity values.

The procedure is then as usual: Set zero point and adjustment to reference, then switch to "Operation" and bring the pointer to zero in the middle of the scale by means of the adjustable part of the fixed capacitance. When the fixed condensers are very small the reference adjustment should be done in accordance with the adjustment curves on p. 26. The following table shows ranges and adjustments to reference for various fixed standards chosen as powers of 10.

Fixed Capacitors	Direct Reading Range	Adjustment to Reference %
2 × 100 pF	0— 1,5 pF	1,17
	0— 8 „	5,77
	0— 35 „	22,0
2 × 1000 pF	0— 15 „	1
	0— 80 „	5
	0— 350 „	20
2 × 0,01 μF	0— 150 „	1
	0— 800 „	5
	0— 3500 „	20
2 × 0,1 μF	0— 1500 „	1
	0— 8000 „	5
	0—35000 „	20
2 × 1 μF	0— 15 nF	1
	0— 80 „	5
	0— 0,35 μF	20
2 × 10 μF	0— 0,15 „	1
	0— 0,80 „	5
	0— 3,5 „	20

Direct-Reading Measurements of Resistances.

In a similar way as for capacitances it is possible to use the Deviation Bridge as a direct-reading ohmmeter. As illustrated in fig. 15 two fixed resistors have to be used, but the resistance under test has to be connected in series with one of the fixed resistances. The small adjustable fraction of the other fixed R may be connected either in series or in parallel with R. If series connection is used, the adjustable R need only be a few per cent

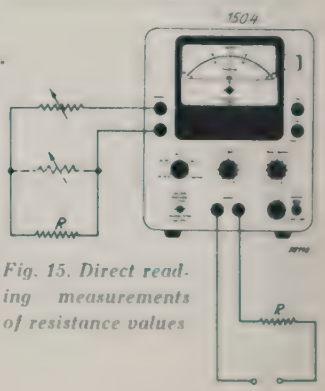


Fig. 15. Direct reading measurements of resistance values

of the total value of the fixed resistance, while it has to be great compared to the total resistance if connected in parallel.

Fixed Recistance	Direct Reading Range	Adjustment to Reference %
2 × 10 Ω	0— 0,15 Ω	1
	0— 0.8 „	5
	0— 3,5 „	20
2 × 100 kΩ	0— 1,5 „	1
	0— 8 „	5
	0— 35 „	20
2 × 1 kΩ	0— 15 „	1
	0— 80 „	5
	0—350 „	20
2 × 10 kΩ	0— 0.15 kΩ	1
	0— 0,8 „	5
	0— 3,5 „	20
2 × 100 kΩ	0— 1,5 „	1
	0— 8 „	5
	0— 35 „	20
2 × 1 MΩ	0— 15 „	1
	0— 80 „	5
	0—350 „	20
2 × 10 MΩ	0— 0.15 MΩ	1,35
	0— 0.8 „	6.73
	0— 3.5 „	27.2

Loss in capacitors.

Most paper condensers have a tan δ of approx. 1 %. The loss can easily be measured with the bridge on its + 1.5 % range, provided that the standard has negligible loss and the capacity of the measuring object is also within that deviation from the capacity of the standard. If the paper condensers are only within the usual tolerance of ± 10 %, the bridge must be set to impedance measurement, and the standard condenser adjusted to give 0 reading on the meter. After that, the swich is depressed to phase angle measurements, and the tan δ is read off the scale. The loss of high-K ceramic condensers will also be within the range of the bridge, whereas the loss in low K ceramic and polystyrene condensers is too small to be measured by that method.

Adjustment of L and Q for inductors.

A standard inductor is used as the standard, and the measuring object is

connected to the "Unknown" terminals. With the switch on "Impedance" the inductance is adjusted to give zero reading. The switch is then set to "Phase Angle" and the Q of the inductor is adjusted (with series or parallel resistors or by some other appropriate method) to give 0 phase angle deviation. In some cases the L and Q adjustments are not independent of each other and the procedure should be repeated to give the best results.

Checking a Tube's Transconductance and Internal Resistance.

For many applications, for example d.c. amplifier, scaling units for calculating machines, and so on, it is important that those tubes which are employed in the construction have definite values with narrow tolerances for both transconductance and internal resistance. Deviation Bridge type 1504 will here give complete satisfaction in the control and choice of suitable tubes.

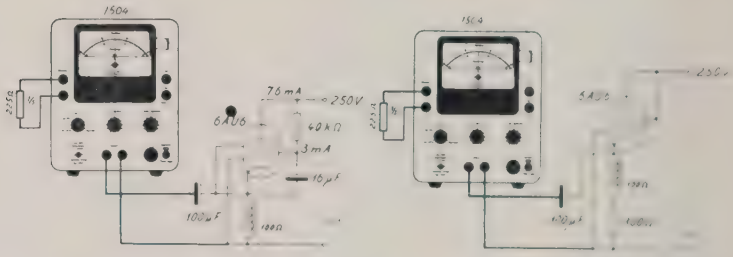


Fig. 16. Measuring transconductance of a 6AU6 tube connected respectively as pentode and triode.

Fig. 16 shows a typical set-up for measuring a tube's transconductance, the tube being connected respectively as pentode and triode. The indicated resistance values are suitable for tube type 6AU6.

If other tube types have to be measured, the components as shown in the diagram must naturally be changed in value to suit. It is important that the choke coil shown in the anode lead of the diagram has an impedance which is great in relation to the tube's reciprocal transconductance at the measuring frequency of 1000 c/s. In the same way, the impedance of the coupling condenser which connects the tube set up to the bridge (the 100 µF condenser in the diagram) should have a value which is small in relation to the reciprocal transconductance. By choosing as standard resistor a value of 225 Ω, the bridge pointer will indicate 0 if the 6AU6 tube has the transconductance given in the catalogue.

Tube No.	Per Cent Deviation of Transconductance								Per Cent Deviation of Internal Resistance							
	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.
1.	+10%	+ 8%	+ 4%	÷ 3%	+ 5%	+ 4%	+10%	÷12%	÷14%	÷17%	+ 3%	÷23%	÷ 25%	÷ 13%	÷ 10%	÷ 4%
2.	+ 7%	+11%	+ 7%	+ 3%	+ 2%	÷ 1%	+ 7%	÷ 6%	÷17%	÷ 6%	+10%	÷25%	÷25%	÷ 3%	÷ 9%	÷ 8%
3.	+ 9%	+ 8%	+ 7%	÷ 5%	÷ 1%	0	0	0	÷10%	+ 5%	÷15%	÷25%	÷25%	÷11%	÷ 1%	÷21%
4.	+ 3%	+15%	0	÷ 1%	÷10%	÷ 9%	+11%	+ 8%	÷11%	÷ 1%	÷ 1%	÷25%	÷25%	÷ 9%	÷12%	÷10%
5.	+ 9%	+16%	+ 6%	÷ 3%		+ 4%	÷ 8%	÷ 2%	÷10%	÷10%	+15%	÷25%		÷13%	÷ 8%	÷ 5%
6.	+16%	+15%	+ 2%	+ 7%		+ 2%	+ 7%	+ 8%	÷14%	÷11%	+ 9%	÷25%		÷11%	÷ 5%	÷25%
7.	+ 2%	+ 2%	+10%			+ 8%	+15%	+ 1%	÷14%	÷ 4%	÷ 1%			÷20%	÷ 7%	÷18%
8.	+13%	+ 8%	÷ 1%			÷ 1%	÷ 3%		÷25%	÷17%	0			÷12%	÷ 9%	
9.	+15%	+ 8%	÷ 2%			+ 2%	+10%		÷16%	÷ 2%	+ 5%			÷11%	÷13%	
10.	+14%		÷ 5%			÷ 2%			÷ 9%		+ 5%			÷12%		
Average	+ 9.8%	+10.1%	+ 2.8%	÷ 0.3%	÷ 1%	+ 0.7%	+ 7.9%	−0.43%	÷ 14%	÷ 7%	÷ 3.2%	÷ 24.7%	−25%	11.5%	÷ 8.2%	−13%

Table III. Examples of measurements of internal resistance and transconductance of 6AU6 tube connected as pentode.

Tube No.	Per Cent Deviation of Transconductance								Per Cent Deviation of Internal Resistance							
	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.	HYTRON	MAZDA A	PHILIPS	RCA	SYLVANIA	TUNGSRAM	MAZDA B	G. E.
1.	+25%	+26%	+19%	+8%	+22%	+23%	+23%	+4%	+4%	+9%	+5%	+17%	+8%	11%	18%	+22%
2.	+20%	+20%	+23%	+18%	+21%	+16%	+24%	+12%	+3%	+7%	+6%	+1%	+4%	3%	16%	+3%
3.	+23%	+25%	+27%	+8%	+17%	+19%	+8%	+17%	+5%	+9%	+12%	+20%	+4%	5%	0	+5%
4.	+19%	+26%	+20%	+14%	+9%	+15%	+25%	+20%	+7%	+14%	+1%	+5%	+15%	6%	15%	+5%
5.	+23%	+26%	+17%	+8%		+27%	+25%	+18%	+9%	+16%	+8%	+9%		10%	15%	+5%
6.	+31%	+29%	+18%	+23%		+25%	+22%	+18%	+9%	+13%	+4%	+3%		13%	11%	+4%
7.	+19%	+16%	+22%			+30%	+29%	+21%	+7%	+15%	+1%			11%	13%	0
8.	+26%	+27%	+21%			+21%	+22%		+1%	+12%	0			+9%	+9%	
9.	+28%	+22%	+13%			+23%	+24%		+3%	+10%	+9%			+9%	+14%	
10.	+19%		+10%			+22%			+7%		+14%			+9%		
Average	+23.3%	+18.3%	+19%	+13.2%	+17.2%	+22.1%	+22.4%	+15.7%	+1.7%	+10.5%	+2.2%	+8.8%	+7.7%	+8.6%	+11.1%	+0.8%

Table IV. Examples of measurements of internal resistance and transconductance of 6AU6 tube connected as triode.

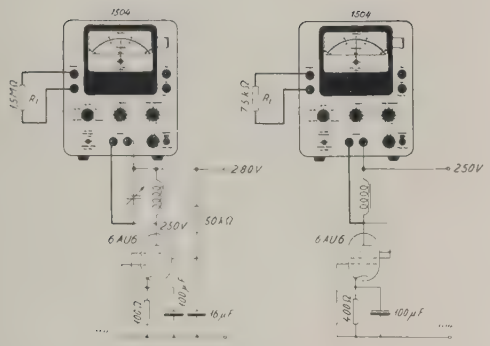
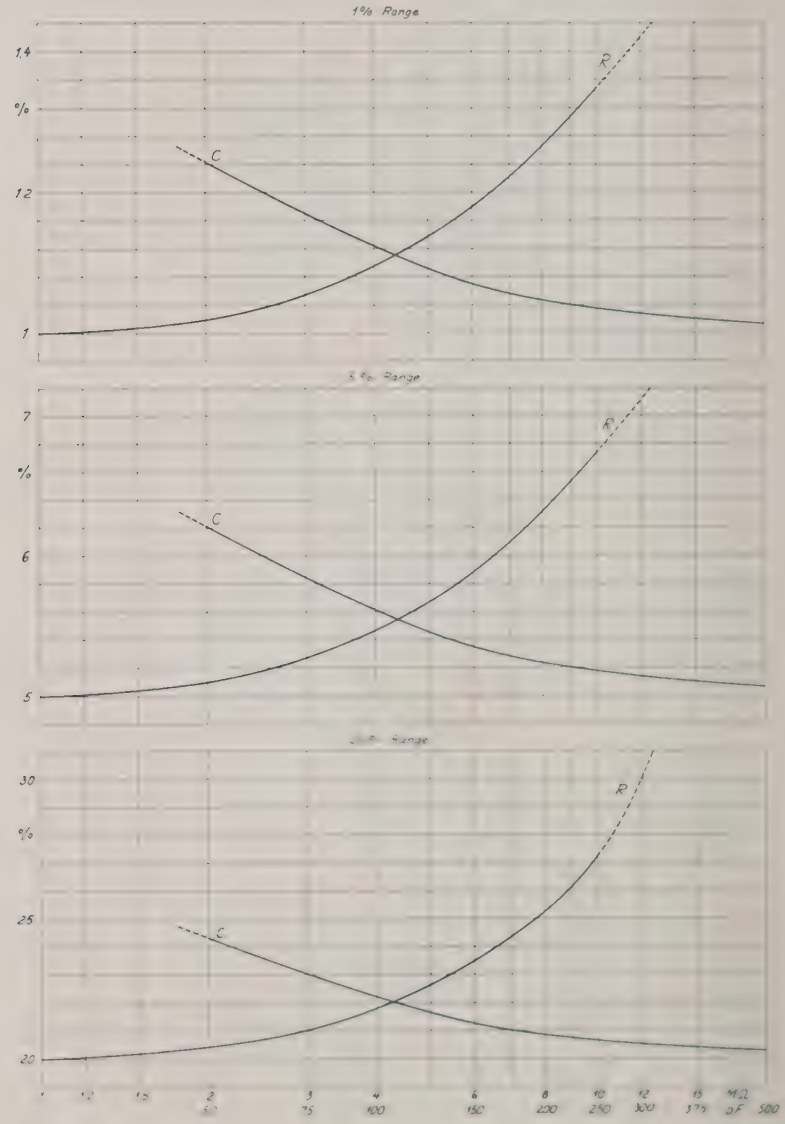


Fig. 17. Measuring internal resistance of 6AU6 tube connected respectively as pentode and triode.

Fig. 17 shows the corresponding set-up for measuring a tube's internal resistance, and here it is important that the impedance in the tube's anode circuit should be much greater that the tube's internal resistance. Therefore, when the tube is connected up as a pentode, it is expedient to produce resonance in the anode impedance.

Corrections Curves for Range Adjustment



Specification

Ranges of Test Components with Deviation Measurements:

Resistance: 10 Ω—10 MΩ
Capacitance: 50 pF—10 μF
Inductance: 2 mH—100 H

Ranges of Test Components with Two External Standards and Direct Reading:

Resistance Range from 0—0,15 Ω to 0—3,5 MΩ
Capacitance Range from 0—0,75 pF to 0—35 μF

Measurement Frequency: 1000 c/c.

Meter: Large moving-coil instrument in which removable scales can be inserted (see figure). Illuminated scale with zero point in the centre. The instrument is safeguarded against overloads. Ranges for impedance deviations from $\div$ 1,5 % to + 1,5 %, $\div$ 7 % to + 8 % and $\div$ 25 % to + 35 % and for phase angle deviations from $\div$ 1,5 to + $1{,}5 \cdot 10^{-2}$, $\div$ 7 to + $7 \cdot 10^{-2}$ and $\div$ 25 to + $25 \cdot 10^{-2}$ radians.

Accuracy of impedance measurements: Better than 0.03 % for deviations close to zero with zero phase angle difference of standard and unknown: Better than 3 % of indicated deviation at full scale deflection.

Max. Speed of Operation: 4000 units per hour.

Stability: The zero point is independent of the line voltage. Deflections from the zero point will change 2 % for a 10 % variation of line voltage.

AC-Hum: The bridge is not sensitive to hum voltages.

Impedance — Phase Angle Switch: A special micro switch is included to allow speedy switching from impedance to phase angle measurements.

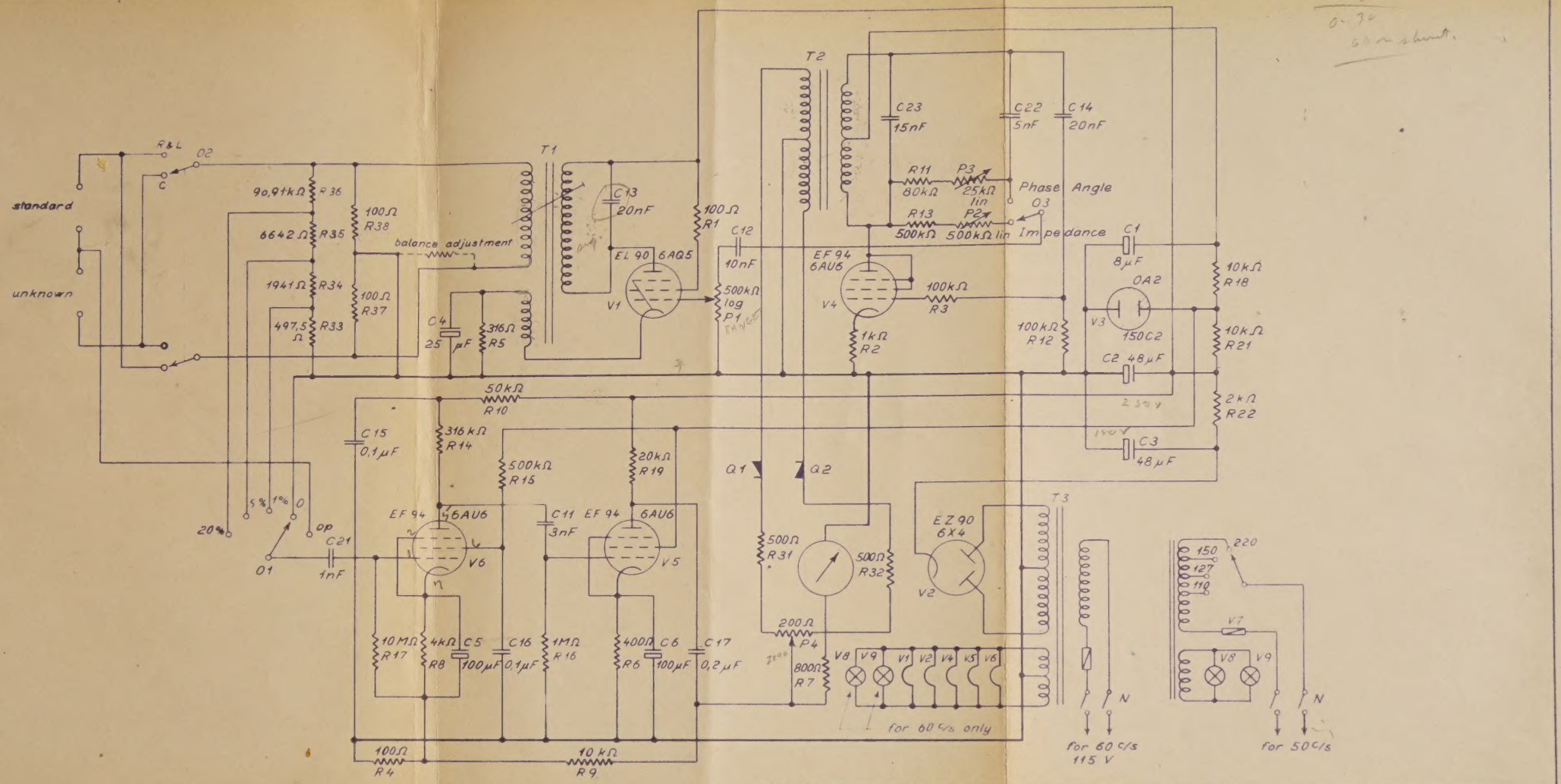
Tubes: 3×6AU6 (EF94), 6AQ5 (EL90), 6X4 (EZ90), OA2 (150C2).

European Model:
Power Supply: 115—127– 150—220 Volts a.c. 40—120 c/s. 40 Watts.

American Model:
Power Supply: 115 Volts a.c. 60 c/s. 40 Watts.

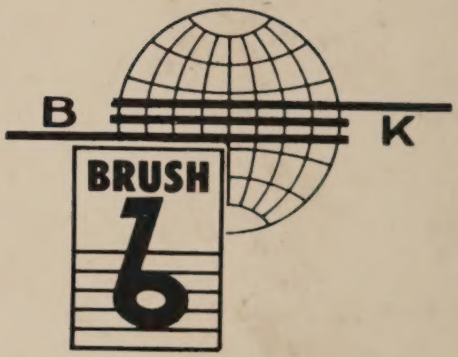
Dimensions: 33 (height) × 28 (width) × 20,5 (depth) excl. dials cm.
13 (height) × 11 (width) × 8 (depth) excl. dials inch.

Weight: 10 kg or 22 lbs.



15-1-55				Deviation Bridge	Brüel & Kjær Copenhagen.
				Type 1504	p 50 Date 15-12-54

GROUND COMMUNICATIONS SECTION



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